PATENT
Howrey Docket No. 01827.0043.00US00
00CXT0362

ITERATIVE CARRIER PHASE TRACKING DECODING SYSTEM

RELATED APPLICATIONS

This application is related to (1) "SYSTEM FOR PERFORMING CARRIER PHASE TRACKING OF CHANNEL SYMBOLS USING RELIABILITY METRICS IN THE TRACKING LOOP," U.S. Patent Application Serial No. Not Yet Assigned, Howrey Dkt. No. 01827.0042.00US00, Conexant Dkt. No. 00CXT0361D, filed November 17, 2000 and owned in common by the assignee hereof; and (2) "RATE N/N SYSTEMATIC, RECURSIVE CONVOLUTIONAL ENCODER AND CORRESPONDING DECODER," U.S. Patent Application Serial No. 09/602,690, filed June 23, 2000, Howrey Dkt. No. 01827.0037.00US00, Conexant Dkt. No. 00CXT0357D, both of which are hereby fully incorporated by reference herein as though set forth in full.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention generally relates to carrier phase tracking, and, more specifically, to an iterative carrier phase tracking decoding system using a serial turbo decoder.

2. Related Art

The carrier phase of a signal can meander with time, due to instabilities in the transmitter upconversion circuitry, or instabilities in the demodulator oscillator and downconversion circuitry. The presence of this phase noise degrades the performance of a receiver, by creating a phase rotation in the actual signaling constellation with respect to the assumed signaling constellation. Since the phase noise typically varies

at a much slower rate than the transmitted symbol rate, this phase noise trend can often be estimated (e.g. "tracked"), and subsequently compensated for by circuits within the receiver. However, at low SNRs (i.e., E_s/N_o values), such as those at which turbo decoders operate, this phase noise can be difficult to accurately track and compensate for, because the phase trend is difficult to distinguish from the noise. For example, at low E_s/N_0 values, uncoded 8-PSK symbol error rates of 20-30% have been experienced. At such high error rates, decision-oriented phase tracking loops within a conventional demodulator can experience great difficulty in following phase trends. Since phase tracking is imperfect, the result is a higher than desired bit error rate (BER). Even if the phase trend can be tracked, current phase tracking loops may only be sufficient to prevent cycle slippage of the signal constellation. A significant amount of phase error may still be present in the received symbols.

SUMMARY

This invention provides an iterative carrier phase tracking system employing a turbo decoder of serially concatenated codes (hereinafter referred to as “serial turbo decoder”). The system employs a tracking loop comprising the series combination of a serial turbo decoder, a tracking loop module, and a derotator. Prior to a particular iteration of the system, a block of symbols is stored in a buffer. The output of the buffer is input to the serial turbo decoder. For one or more symbols in the block, the serial turbo decoder forms an estimate of the symbol, and, optionally, a reliability metric for the estimate. The estimates (and reliability metrics if produced) for the one or more buffered symbols are input to the tracking loop module. Responsive thereto, the tracking loop module determines a residual between one or more of the buffered symbols and its corresponding estimate. If reliability metrics are produced, the tracking loop module may weight one or more of the residuals by its corresponding reliability metric. The tracking loop module then determines a derotation phase for

one or more of the symbols in the block responsive to one or more of the weighted or unweighted residuals for the block. Derotation phases for one or more of the symbols in the block are input to the symbol derotator. The symbol derotator derotates one or more of the symbols in the block by its corresponding derotation phase. To ensure proper synchronization, a first delay element may be provided between the output of the buffer and the symbol derotator, and a second delay element may be provided between the output of the buffer and the tracking loop module. The first delay element compensates for any delay through the serial turbo decoder and the tracking loop module, and the second delay element compensates for any delay through the serial turbo decoder. One or more of the derotated symbols output from the symbol derotator are then stored back in the buffer, replace the previously buffered symbols, and become the buffered symbols for the next iteration. At this point, another iteration may commence. After a prescribed number of iterations, estimates of the underlying source bits are output by the serial turbo decoder.

In one example, a weighted windowing technique may be used in which, during a particular iteration p, the derotation phase for the ith symbol in the block, θ_i^p, is derived from a plurality of residuals which are within a sliding window. The residuals may be any values derived from a comparison of the symbols with their corresponding estimates, including, without limitation, phase residuals, or residuals comprising the components of the symbols which are orthogonal to the corresponding symbol estimates. The window may extend on either side of the symbol because of the non-causal nature of the technique. In one example, the calculation of θ_i^p during a particular iteration p may be expressed through the following equation:

$$\theta_i^{\,p} = \sum_{j=i-W/2}^{j=i+W/2} z_j^{\,p} \bullet w_j$$

where W is the size of the window, in terms of number of symbols; z_j^p is a residual determined during iteration p between a buffered symbol r_j^p and the corresponding

estimate of that symbol s_j^p; and w_j is the weight assigned to the jth residual z_j^p. The weights w_j may follow a predefined phase-noise filter mask. Also, as stated above, the residual z_j^p may be, without limitation, the phase residual e_j^p between r_j^p, the jth buffered symbol, and s_j^p, the estimate of that symbol; or the orthogonal component residual y_j^p, which is the component of r_j^p which is orthogonal to s_j^p.

In another example, the reliability metrics may also used to compute the derotation phases in accordance with the following expression:

$$\theta_i^p = \frac{\sum_{j=i-W/2}^{j=i+W/2} z_j^p \bullet w_j \bullet R_j^p}{\sum_{j=i-W/2}^{j=i+W/2} w_j \bullet R_j^p}$$

In the foregoing, the parameters θ_i^p, z_j^p, and w_j are as defined previously. The parameter R_j^p is the reliability metric for the jth symbol estimate determined during iteration p.

In a third example, a technique may be employed in which the derotation phases are computed in accordance with the following equation:

$$\theta_k^p = \sum_{i=1}^{N} a_i \bullet \theta_{k-i}^p + \sum_{i=0}^{M-1} b_i \bullet R_{k-i}^p \bullet z_{k-i}^p$$

In this expression, θ_k^p is the derotation phase for the kth symbol determined during the pth iteration, θ_{k-i}^p represents the derotation phase for the (k-i)th symbol during the pth iteration, a_i is a coefficient applied to θ_{k-i}^p, z_{k-i}^p is a residual derived during the pth iteration from a comparison of the (k-i)th symbol, r_{k-i}^p, with the estimate for that symbol, s_{k-i}^p, R_{k-i}^p is the reliability metric for the estimate of the (k-i)th symbol during the pth iteration, b_i is a coefficient applied to $R_{k-i}^p \bullet z_{k-i}^p$, and N and M are non-negative integers.

Other systems, methods, features and advantages of the invention will be or will become apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the invention and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE FIGURES

The invention can be better understood with reference to the following figures. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. Moreover, in the figures, like reference numerals designate corresponding parts throughout the different views.

Figure 1 is a block diagram of an iterative carrier phase tracking decoding system in accordance with the subject invention.

Figure 2 is a flowchart of a method of operation of the system of Figure 1.

Figure 3 is a block diagram of a serial turbo decoder.

Figure 4 is a flowchart of a method of operation of the serial turbo decoder of Figure 3.

DETAILED DESCRIPTION

A. Embodiments of the Invention

An embodiment of an iterative carrier phase tracking decoding system 100 in accordance with the subject invention is illustrated in Figure 1. This embodiment employs a tracking loop comprising the series combination of serial turbo decoder 108, tracking loop module 116, and symbol derotator 112. The system is configured to buffer a block of symbols, and then iteratively derotate the block of symbols to reduce or eliminate phase error with the carrier. In addition, the system is configured to iteratively decode the symbols into their underlying source bits. A controller (not

shown) may be provided to direct the system through its multiple iterations. In one application, the system may function as the decoder 108 in the system of Figure 1 of Howrey Dkt. No. 01827.0042.00US00, Conexant Dkt. No. 00CXT0361D, previously incorporated by reference. In this application, the decoder reduces or eliminates carrier phase error in the symbols over and above that removed by the carrier tracking module 106 in Figure 1 of Howrey Dkt. No. 01827.0042.00US00. It should be appreciated, however, that other applications of the system are possible. For example, an application is possible where carrier tracking module 106 is eliminated in the system of Figure 1 of Howrey Dkt. No. 01827.0042.00US00, and the system 100 is coupled to demodulator 104. In this application, the system could be the sole means for reducing or eliminating carrier phase error in the received symbols.

The system is initialized when a block of L symbols is stored in buffer 104, where L is an integer greater than or equal to 1, over one or more signal lines 102. These symbols may originate from carrier tracking module 106 in Figure 1 of Howrey Dkt. No. 01827.0042.00US00 or from some other source. The symbols may be encoded with a serial concatenated convolutional coder (SCCC) or serial concatenated trellis coded modulation coder (SCTCM) such as that described or referred to in "Serially Concatenated Trellis Coded Modulation with Iterative Decoding: Design and Performance," by S. Benedetto, D. Divsalar, G. Montorsi, and F. Pollara, in IEEE Communications Theory Mini Conference associated with Globecom '97, pp. 38-43, 1997, which is hereby fully incorporated by reference herein as though set forth in full.

The output of the buffer comprises a block of L symbols which can be referred to using the notation r_k^p, where the subscript k, $1 \le k \le L$, refers to the position of a particular symbol in the block, and the superscript p refers to the pth iteration. If the pth iteration is the first iteration of the system, as discussed, the output of the buffer will be the initially stored block of symbols received over the one or more signal lines

102. If the pth iteration of the system is not the first iteration of the system, the output of the buffer will be the derotated block of symbols stored in the buffer during the previous iteration over one or more signal lines 114.

During a particular iteration p, the buffered block of symbols, whatever their source, is then provided over one or more signal lines 106 to serial turbo decoder 108. Responsive thereto, serial turbo decoder 108 provides, on one or more signal lines 118, a block of estimates s_k^p, $1 \leq k \leq L$, such that an estimate is provided for each of the symbols in the block. In addition, serial decoder 108 may optionally provide, over one or more signal lines 120, a block of reliability metrics R_k^p, $1 \leq k \leq L$, such that a reliability metric is provided for each of the symbol estimates. The symbol estimates s_k^p, and optionally the reliability metrics R_k^p, are input to tracking loop module 116. In addition, the buffered symbols r_k^p are input to the tracking loop module 116 after passage through delay element 126. Delay element 126 is configured to compensate for any delay through serial turbo decoder 108, and allow proper synchronization between all the inputs to tracking loop module 116.

Responsive to this information, tracking loop module 116 computes, for each symbol r_k^p, a residual z_k^p between a buffered symbol r_k^p and the estimate s_k^p of that symbol. If reliability metrics R_k^p are produced, the tracking loop module 116 may weight one or more of the residuals z_k^p with the reliability metric R_k^p for the corresponding estimate s_k^p. Responsive to one or more of the weighted or unweighted residuals, the tracking loop module will determine a complex exponential based on the derotation phase, $\exp(j\theta_k^p)$, for each of the symbols in the block. These complex exponentials are input to complex conjugate block 128, which determines the complex conjugates $\exp(-j\theta_k^p)$ of the complex exponentials. These complex conjugates are input to symbol derotator 112 over one or more signal lines 122. Symbol rotator 112 derotates each symbol in the block by its corresponding derotation phase. In one implementation, where the symbols are embodied as a quadrature

baseband signal, the symbol derotator is a modulator, which is configured to multiply the baseband signal by the complex conjugates $\exp(-j\theta_k^p)$.

To ensure proper synchronization, delay element 110 is provided between the output of buffer 104 and derotator 112. This delay element compensates for delay through serial turbo decoder 108 and tracking loop module 116. After derotating the symbols in the block, derotator 112 stores the resulting derotated symbols t_k^p back in buffer 104. These derotated symbols t_k^p replace the previously buffered symbols r_k^p, and become the buffered symbols r_k^{p+1} for use in the next iteration. This completes the pth iteration of the system. The foregoing process may then repeat for additional iterations until, e.g., a prescribed number of iterations has been completed. After this has been accomplished, serial turbo decoder 108 provides estimates of the underlying source bits over signal line 124.

In one example, a weighted windowing technique may be employed to determine the derotation phases. According to this technique, the derotation phase θ_k^p for the ith buffered symbol in the block, r_k^p, $1 \le k \le L$, during the pth iteration may be derived from residuals z_k^p within a sliding window which may extend to positions on either side of the symbol in question because of the non-causal nature of the technique. In one example, the calculation of θ_i^p, $1 \le i \le L$, may be expressed as follows:

$$\theta_i^p = \sum_{j=i-W/2}^{j=i+W/2} z_j^p \bullet w_j \qquad (1)$$

where W+1 is the size of the window, in terms of number of symbols; z_j^p, $1 \le j \le L$, is a residual between a buffered symbol r_j^p, $1 \le j \le L$, and the corresponding estimate of that symbol s_j^p, $1 \le j \le L$; and w_j is the (filter) weight assigned to the jth residual z_j^p. The weights w_j may, in some instances, follow a time domain representation of a

predefined phase-noise mask. These weights are assumed normalized, such that $\sum_{j=i-W/2}^{j=i+W/2} w_j = 1$.

Depending on the application, the residual z_j may be without limitation a phase residual, e_j^p, $1 \leq k \leq L$, between r_j^p, $1 \leq k \leq L$, and s_j^p, $1 \leq k \leq L$; or an orthogonal component residual y_j^p, i.e., the component of r_j^p orthogonal to s_j^p. Other examples are possible. These concepts are explained in detail in Howrey Dkt. No. 01827.0042.00US00, Conexant Dkt. No. 00CXT0361D, previously incorporated by reference.

In another example, reliability information R_k^p, $1 \leq k \leq L$, for the symbol estimates s_k^p, $1 \leq k \leq L$, may also be used to determine the derotation phases. In accordance with this technique, the derotation phase θ_i^p, $1 \leq i \leq L$, may be expressed as:

$$\theta_i^p = \frac{\sum_{j=i-W/2}^{j=i+W/2} z_j^p \bullet w_j \bullet R_j^p}{\sum_{j=i-W/2}^{j=i+W/2} w_j \bullet R_j^p} \qquad (2)$$

In the foregoing, the parameters θ_i^p, z_j^p, and w_j are as defined previously. The parameter R_j^p, $1 \leq j \leq L$, is the reliability metric of the jth symbol estimate during the pth iteration.

In one implementation, only a subblock of the r_k^p (from which the z_k^p) are formed) during a particular iteration need be kept in active storage. Once θ_k^p is computed, it may be used to derotate the corresponding r_k^p, and thus update the value to be processed in the next iteration. Thus updated datum is denoted by r_k^{p+1}.

In a third example, a technique may be employed where the derotation phase for the kth symbol in the block, θ_k^p, may be computed in accordance with the following equation:

$$\theta_k^{\,p} = \sum_{i=1}^{N} a_i \bullet \theta_{k-i}^{\,p} + \sum_{i=0}^{M-1} b_i \bullet R_{k-i}^{\,p} \bullet z_{k-i}^{\,p} \qquad (3)$$

In this expression, θ_k^p is the derotation phase for the kth symbol in the block, $1 \leq k \leq L$, during the pth iteration, θ_{k-i}^p represents the derotation phase for the (k-i)th symbol, during the pth iteration, a_i is a coefficient applied to θ_{k-i}^p, z_{k-i}^p is a residual derived from a comparison of the (k-i)th buffered symbol, r_{k-i}^p, with an estimate of that symbol, s_{k-i}^p, R_{k-i}^p is the reliability metric for the estimate of the (k-i)th symbol during the pth iteration, b_i is a coefficient applied to $R_{k-i}^p \bullet z_{k-i}^p$, and M and N are non-negative integers. Again, depending on the application, the residual z_{k-i}^p may be a phase residual, e_{k-i}^p or an orthogonal component residual y_{k-i}^p, i.e., the component of r_{k-i}^p orthogonal to s_{k-i}^p.

Examples of this technique are described in Howrey Dkt. No. 01827.0043.00US00. Conexant Dkt. No. 00CXT0361D. In one such example, the tracking loop has a loop bandwidth which may vary from symbol to symbol responsive to $R_k^p \bullet z_k^p$, where R_k^p is the reliability metric for the estimate of the kth symbol during the pth iteration, and z_k^p is the residual corresponding to the kth symbol during the pth iteration. In one implementation, the loop may be implemented as a digital filter or digital loop with modifiable loop parameters.

A flowchart of a method of operation of the system of Figure 1 is illustrated in Figure 2. The method begins with step 304, in which estimates s_k^p, $1 \leq k \leq L$, of a block of buffered symbols r_k^p, $1 \leq k \leq L$, are provided. This step may be performed by a serial turbo decoder. Step 304 is followed by step 306, in which reliability metrics R_k^p, $1 \leq k \leq L$, for the symbol estimates s_k^p, $1 \leq k \leq L$, are optionally provided. Again, this step may be performed by a serial turbo decoder.

Step 306 is followed by step 308, in which residuals $z_k^p, 1 \leq k \leq L$, between the buffered symbols $r_k^p, 1 \leq k \leq L$, and the symbol estimates s_k^p, $1 \leq k \leq L$, are provided. These residuals may be without limitation phase residuals e_k^p, $1 \leq k \leq L$, or orthogonal

component residuals, y_k^p, $1 \le k \le L$, that is, the components of the buffered symbols r_k^p, $1 \le k \le L$, orthogonal to the corresponding symbol estimates s_k^p, $1 \le k \le L$.

Step 308 is followed by step 310, in which the residuals z_k^p, $1 \le k \le L$, are optionally weighted by the corresponding reliability metrics, R_k^p, $1 \le k \le L$.

Step 310 is followed by step 312, in which the derotation phases θ_k^p, $1 \le k \le L$, are determined responsive to one or more of the weighted or unweighted residuals, and possibly other parameters such as one or more previous values of the derotation phases. Examples of this step are represented by any of the equations (1), (2), or (3) presented earlier.

Step 312 is followed by step 314, in which the buffered symbols r_k^p, $1 \le k \le L$, are derotated by their corresponding derotation phases θ_k^p, $1 \le k \le L$. Step 314 is followed by step 316, in which the derotated symbols t_k^p, $1 \le k \le L$, are stored back in the buffer, replacing the symbols r_k^p, $1 \le k \le L$, and becoming the symbols r_k^{p+1}, $1 \le k \le L$, for use in the next iteration. Step 316 is followed by step 318 in which a query is made whether the prescribed number of iterations of the system has been completed. If the answer is no, a jump is made back to step 304 to begin the next iteration. If the answer is yes, the process proceeds to step 320, where estimates of the underlying source bits are provided. Again, this step may be performed by a serial turbo decoder. The process then completes.

B. Serial Turbo Decoders

A block diagram of one embodiment of a serial turbo decoder is illustrated in Figure 3. As illustrated, two instances of a four port device known as a soft input soft output (SISO) module are employed in the decoder. The first such module is inner SISO 500, and the second such module is outer SISO 506.

Each such module may have two inputs, a coded (C) symbol input, and an uncoded (U) bit input, and two outputs, a coded (C) symbol output, and an uncoded (U) bit output. The coded symbols to be decoded are input over one or more signal

lines 502 to the C input of inner SISO 500. One or more signal lines 502 corresponds to one or more signal lines 106 in Figure 1, and one or more signal lines 206 in Figure 2. A priori information from interleaver 508 is provided over one or more signal lines 510 to the U input of inner SISO 500. The inner SISO 500 employs a soft output algorithm, such as a MAP (Maximum A Posteriori) algorithm, or an algorithm providing similar functionality, such as a log-MAP algorithm, or a SOVA (Soft Output Viterbi Algorithm) to determine estimates of each coded symbol and the underlying source bits. From these estimates, the inner SISO produces extrinsic information regarding the source bits and a posteriori estimates of the coded symbols. It provides a posteriori estimates of the coded symbols on its C output (one or more signal lines 118 in Figure 1; one or more signal lines 218 in Figure 2). It outputs the extrinsic information regarding the uncoded source bits on its U output. Inner SISO 500 may also output, on one or more signal lines 514, reliability metrics for each of the symbol estimates. One or more signal lines 514 corresponds to one or more signal lines 120 in Figure 1, and one or more signal lines 220 in Figure 2.

The information output on the U output of inner SISO 500 is passed through de-interleaver 504, and then input to the C input of outer SISO 506. The information output on the C output of inner SISO 500 is output on one or more signal lines 512. In the example shown, the U input of outer SISO 506 is not used.

The outer SISO 506 also employs a soft output estimation procedure (such as MAP, log-MAP, SOVA, or a functional equivalent) to compute a posteriori estimates of the coded symbols. The a posteriori estimates of the coded symbols are output on the C output of the outer SISO 506. The a posteriori estimates output on the C output of outer SISO 506 are passed through interleaver 508, and then provided, over one or more signal lines 510, to the U input of inner SISO 500. This information acts as a priori information to the inner SISO 500.

After a prescribed number of iterations, outer SISO 506 provides, over one or more signal lines 516, estimates of the source bits, again using a soft output procedure (such as MAP, log-MAP, SOVA, or a functional equivalent). Prior to this time, in the example shown, the U output of outer SISO 506 is not typically used or computed.

Figure 4 illustrates an embodiment of a process employed by the decoder of Figure 3. In step 600, within the inner SISO 500, extrinsic information relating to uncoded source bits is derived. This step may include estimating the source bits, and then subtracting the a priori information regarding the source bits provided at the U input to inner SISO 500.

Step 600 is followed by step 602. In step 602, the extrinsic information derived in the previous step is provided as a priori information to the C input of outer SISO 506 after passage through de-interleaver 504.

Step 602 is followed by step 604 where, in the inner SISO 500, extrinsic information relating to estimates of the coded symbols is derived. This step may include estimating the coded symbols, and then subtracting the a priori information provided to the U input of inner SISO 500. This step may also include deriving likelihood information regarding the symbol estimates.

Step 604 is followed by step 606, where the extrinsic information relating to the symbol estimates is output over one or more signal lines 512. This step may also include outputting the reliability metrics for the symbol estimates over one or more signal lines 514.

Step 606 is followed by step 608, where, in the outer SISO 506, extrinsic information regarding the coded channel symbols is derived. This step may include estimating the channel symbols and then subtracting the a priori information regarding channel symbols provided to the C input of outer SISO 506.

Step 608 is followed by step 610, where the extrinsic information regarding coded channel symbols derived in the previous step is provided as a priori information to the U input of inner SISO 500 after passage through interleaver 508.

Step 610 is followed by decision block 612. In decision block 612, it is determined whether additional iterations should be performed. If so, the process is repeated, beginning with step 600. If not, a jump is made to step 614. In step 614, in the outer SISO 506, likelihood information is derived for the underlying source bits. Step 614 is followed by step 616, where estimates of the underlying source bits are derived from the likelihood information.

For more information regarding soft output estimation processes, such as MAP, log-MAP, SOVA, and the like, the reader is referred to "Optimal Decoding of Linear Codes for Minimizing Symbol Error Rate," L.R. Bahl et al., IEEE Transactions on Information Theory, March 1974, pp. 27-30 (hereinafter referred to as "the Bahl reference"); "Near Shannon Limit Error-Correcting Coding and Decoding: Turbo Codes," C. Berrou et al., Proc. ICC '93 Geneva, Switzerland, May 1993, pp. 1064-1070 (hereinafter referred to as "the Berrou reference"); "An Intuitive Justification and a Simplified Implementation of the MAP Decoder for Convolutional Codes," A. Viterbi, IEEE Journal On Selected Areas In Telecommunications, Vol. 16, No. 2, Feb. 1998, pp. 260-264 (hereinafter referred to as "the Viterbi reference"); and "A Viterbi Algorithm with Soft-Decision Outputs and its Applications," J. Hagenauer and P. Hoeher, in Proceedings of IEEE Globecom '89, Dallas, TX, Nov. 1989, pp. 47.1.1-47.1.7 (hereinafter referred to as "the Hagenauer reference"). Each of the Bahl, Berrou, Viterbi, and Hagenauer references is hereby fully incorporated by reference herein as though set forth in full.

C. Additional Embodiments

From the previous section, it can be seen that the serial turbo decoder 108 in the system of Figures 1 is iterative, as is the system itself. Embodiments of the

system of Figure 1 is possible where the iterations of the serial turbo decoder occur in tandem with those of the overall system. Thus, in the system of Figure 1, serial turbo decoder 108 may perform an iteration for each iteration of the overall system.However, it should be appreciated that a tight coupling between the two may not be necessary, and embodiments are possible where the serial turbo decoder iterates many times for each iteration of the overall system. Thus, in the system of Figue 1, serial turbo decoder 108 may perform several iterations for each iteration of the overall system.

Embodiments are also possible where the buffered symbols r_k^P, $1 \leq k \leq L$, are derotated for each iteration of the overall system, or, alternatively, are derotated only for selected iterations of the system. As an example of the latter, recognizing that the estimates of the symbols may become more reliable at the iterations of the system progress, the buffered symbols may be derotated only after a prescribed number of iterations of the system have taken place. On the other hand, recognizing that the carrier phase error may be highest during the initial iterations of the system, the buffered symbols may be derotated only during the initial iterations of the system.

Furthermore, embodiments are possible where iterations of the serial turbo decoder and the overall system occur in tandem, but the symbol estimates and optional reliability metrics from the turbo decoder are available before the iteration of the decoder is completed. Consider, for example, embodiments where the serial turbo decoder of Figure 3 serves as decoder 108 in the system of Figure 1. The symbol estimates s_k^P, $1 \leq k \leq L$, and, optionally, the reliability metrics R_k^P, $1 \leq k \leq L$, may be provided by the inner SISO well before the iteration of the serial turbo decoder has been completed (this typically occurs when the interleaver has provided a priori information to the U input of the inner SISO). This is advantageous, because it allows the tracking loop module to begin processing this information in parallel with the operation of the serial turbo decoder.

Of course, embodiments are also possible where the symbol estimates and optional reliability metrics are derived from an output of the outer SISO rather than the inner SISO. With reference to Figure 3, for example, an embodiment is possible in which the symbol estimates are derived from the output 510 of interleaver 508. In this embodiment, the output 510 of interleaver may be adjusted by first adding back the a priori information provided initially to the C input of outer SISO 506. Hard decisions may be made based on the bits, and this information may then passed through an inner encoder and symbol mapper which corresponds to inner SISO 500. The result of this process is symbol estimates which may be output to the tracking loop module.

While various embodiments of the invention have been described, it will be apparent to those of ordinary skill in the art that many more embodiments and implementations are possible that are within the scope of this invention. Accordingly, the invention is not to be restricted. Accordingly, the invention is not to be restricted except in light of the attached claims and their equivalents.